



Original communication

Are frontal sinuses useful indicators of sex?☆

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ABSTRACT

Accurate sex prediction of skeletonised human remains excludes one-half of the population, enabling a more focussed search of missing persons' files. The skull is useful in sex assessment of skeletonised remains; however, its fragmentation precludes the use of all conventional craniofacial markers. The frontal bone may be recovered intact in fragmented remains and the sinuses therein may be useful in sex differentiation. A total of 100 paranasal sinus view radiographs of 50 males and females each were evaluated for potential differences in frontal sinus configuration following the methods of Yoshino et al. (Forensic Sci Int 1987; 34:289–99.) and Tang et al. (Forensic Sci Int 2009; 183:104.e1–3.). Data were assessed through univariate and multivariate statistics. The univariate Mann–Whitney *U*-test revealed statistically insignificant sexual dimorphism ($p > 0.05$) for the frontal sinuses. Moreover, multivariate logistic regression equations allowed correct sex identification in 60% of cases only. Possible reasons for the low sexual dimorphism may be frontal sinus' high inter-individual variability; also, existing techniques that employ frontal sinus classification systems may lead to a loss of information when features that require visual observation are grouped and assigned class numbers. The results herein suggest that frontal sinuses may have limited application as the sole predictor of sex.

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1. Introduction

Accurate sex identification of skeletal remains is important as it excludes about half of the population – forensic investigators can then focus on retrieving antemortem records of the remainder to establish identification through comparative methods. The skull has been shown as a useful indicator of sex – the various parameters on a skull's surface, such as the supraorbital ridge, nasal aperture and mastoid process, assist in identifying the sex of skeletal remains to high levels of accuracy.¹ However, the skull itself may only be partially recovered on numerous occasions and all conventional markers therein may not always be available for sex assessment. Hence, it may be useful to evaluate alternative structures and determine their accuracy rates in sex prediction.

Frontal sinuses are, typically, paired lobulated cavities located deep to the superciliary arches in the frontal bone. They are either

absent² or insignificant at birth³ but gradually increase in size and reach maximum dimension by about 20 years of age.^{4–6} The structure of the frontal sinuses does not change after this, except under rare occurrences such as fractures, tumours or severe infections⁷; also, in old age, further pneumatization may occur due to atrophic changes.⁴

Frontal sinus patterns are considered to be unique – their configuration has been demonstrated as being highly individualistic^{4,5,8–10} and a potent marker in personal identification.^{11–13} Unsurprisingly, the use of the frontal sinuses in post-mortem identification has been explored for many decades. Attempts to establish this presumed uniqueness have successfully been undertaken through the two- and three-dimensional visualisation of frontal sinuses on radiographs and computed tomography (CT) scans. Indeed, the frontal sinuses can be seen radiographically from as early as 5 years of age.⁷

Since these pneumatic cavities are encased in the frontal bone, which in turn is frequently recovered intact in fragmented skulls or as isolated bones (Fig. 1), their usefulness in predicting sex through radiographic assessment will be beneficial in forensic, anthropological as well as archaeological contexts. Correct sex assessment would be an added use for these structures as they contribute to reconstructive identification of the post-mortem remains, in addition to comparative identification. However, the

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Fig. 1. On occasion, the frontal bone may be the only one recovered and examination of its sinuses may contribute to sex and personal identification.

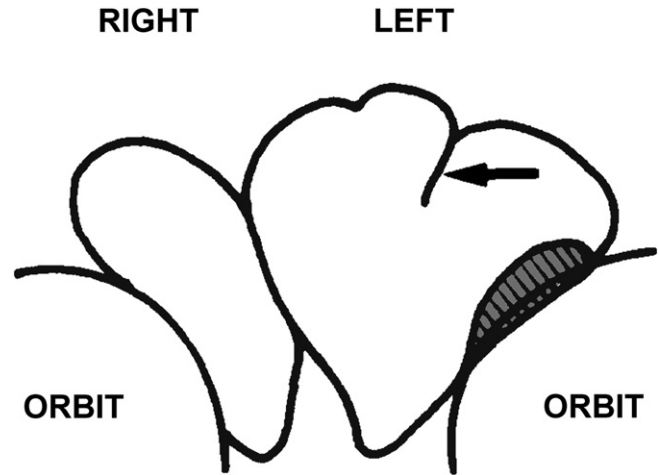


Fig. 2. Schematic drawing of antero-posterior view of the frontal sinus. The upper border is scalloped with 3 arcades on the left and smooth on the right. One partial septum (marked by arrow) is present in the left sinus. The hatched area represents the supraorbital cell (reprinted from Yoshino M et al. Classification system of frontal sinus patterns by radiography. Its application to identification of unknown skeletal remains. *Forensic Sci Int* 1987; 34(4): 289–299, with kind permission of Elsevier).

value of frontal sinuses in sex prediction has been explored only sparsely. Buckland-Wright¹⁴ was one of the earliest to report sex differences, stating that frontal sinuses in “males were approximately twice as large as the females” (p. 516). However, Yoshino et al.⁴ evaluated antero-posterior radiographs and found no significant sexual dimorphism through the application of univariate statistics. Similarly, Cox et al.¹⁰ undertook computer-based assessments of radiograph-traced sinus outlines, but obtained no statistically significant sexual variation. Uthman et al.,¹⁵ on the other hand, examined CT scans, which revealed moderate sexual dimorphism through the use of discriminant function analysis. Today CT is gaining widespread use and gradually replacing conventional radiography. However, considering the common availability and continued usage of two-dimensional radiography in this geographic region, and the relative ease of examining frontal sinus patterns based on existing classifications,⁴ we embarked on assessing sex from radiographs but through the application of more robust statistical methods vis-à-vis those used previously.^{4,15}

2. Materials and methods

The sample comprised of paranasal sinus (PNS)-view radiographs of 100 subjects of Indian origin (50 males and females, each) whose ages ranged between 21 and 54 years. The age was limited to this range as sinus development is completed by about 20 years and atrophic changes in old age can lead to gradual pneumatization,¹⁶ possibly precluding results of sexual dimorphism. The radiographs obtained were indicated for maxillary sinus pathology or mid-facial fracture/trauma, and only those radiographs in which frontal sinuses and their outlines were clearly visible were included. Sex differences in the sinuses were evaluated in terms of the number of scallops on the sinuses' superior border (right, left and total), the number of partial septa (right, left and total), unilateral/bilateral presence or absence of partial septa and unilateral/bilateral presence or absence of supraorbital cells (the latter two features graded as '0' for bilateral absence, '1' for unilateral presence and '2' for bilateral presence). The features graded here follow a slightly modified version of the method of Yoshino et al.⁴ (Fig. 2). In addition, we looked at the number of partial septa on either side, which has also been assessed by Tang et al.¹⁷

The Mann–Whitney *U*-test, a non-parametric test used for evaluating variation in two unrelated samples, was applied to gauge sex differences in these features. To evaluate possible intra-observer differences, the features on the sinuses were re-evaluated by the primary examiner on 30 randomly selected radiographs after a period of 2 months; to assess potential inter-observer variation, a second examiner also evaluated the features on 30 radiographs. Possible observer differences were assessed using the Wilcoxon matched-pairs signed ranks test, a non-parametric test for evaluating differences in two related samples.

To quantify the use of the variables in sex allocation, the data were subjected to logistic regression analysis (LRA), a multivariate statistical approach that has recently seen an increase in usage, and is preferred over other multivariate techniques such as discriminant function analysis (DFA).^{18–21} LRA results in a log-odds or *logit*. A predicted probability (*P*), which falls between 0 and 1, can be derived from the logit using the function $P = 1 / (1 + e^{-L})$, where *L* is the logit of the multiple regression equation (i.e., $L = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n$). The default cut-off in logistic regression is 0.50; hence, a subject with a probability >0.50 would be categorised as male while *P* < 0.50 would be considered as female. The closer the value is to 1, the greater the probability that the subject is male, while a value closer to 0 indicates a greater probability of the subject being female. Two important methods to assess the fit of a logistic model to the data are: (1) computation of the allocation accuracy of the regression model applied to the sample used to develop the equations and (2) a goodness-of-fit statistic, symbolised by the $-2 \log$ likelihood ($-2LL$), which were evaluated in this study. All statistical analyses were performed on the Statistical Package for Social Sciences (SPSS) 17.0 software package (SPSS Inc., Chicago, USA; now IBM Corp., Armonk, USA).

3. Results

Frontal sinuses were visible in most cases in our sample. The incidence of bilateral frontal sinus absence was 2% (one male and female each), right frontal sinus absence was 6% (four males and two females) while the left sinus was missing in 4% of cases (two males and females each).

The Wilcoxon matched-pairs signed ranks test revealed insignificant intra-observer differences for all frontal sinus variables ($P > 0.05$); the same test revealed insignificant inter-observer differences for most variables ($P > 0.05$), the exception being the number of supraorbital cells ($P = 0.002$).

The descriptive statistics and Z values for the male and female frontal sinus variables are depicted in Table 1. Male–female differences were observed in all the assessed variables; however, the Mann–Whitney U -test revealed no statistically significant sexual dimorphism in any of them (Table 1).

The accuracy of sex allocation of LRA is depicted in Table 2. Six of the eight variables entered the analysis, yielding a 60% accuracy rate. (The totals for right and left sinus scallops and right and left partial septa did not enter the LRA.) Males were correctly identified more often than females (Table 2). The goodness-of-fit statistic, the $-2LL$, was 133.35. The lower the $-2LL$ statistic, better the fit of the model to the data.¹⁹ The logistic regression equation derived for the variables was as follows:

- $L = -0.489 - (\text{No. of right sinus scallops} \times 0.167) + (\text{No. of left sinus scallops} \times 0.164) + (\text{No. of right sinus partial septa} \times 0.041) - (\text{No. of left sinus partial septa} \times 0.03) + (\text{Presence/absence of partial septa unilaterally or bilaterally} \times 0.528) - (\text{Presence/absence of supraorbital cells unilaterally or bilaterally} \times 0.162)$.

4. Discussion

Frontal sinus patterns have been evaluated as a parameter to establish post-mortem identity, and empirical data suggest that their configuration is mostly characteristic to each individual.^{8,10} However, their potential use is sex determination has seldom been assessed. Yoshino et al.⁴ did and found no significant univariate sexual dimorphism for the numbers of scallops on the sinuses' superior border, the numbers of partial septa and the number of supraorbital cells – results confirmed in our sample as well. More recently, Tatlisumak et al.⁷ and Tang et al.¹⁷ also examined these variables; however, their assessment explored the

Table 2

Classification results of the logistic regression analysis (LRA).

	Male		Female		Total	
	n	%	n	%	n	%
Frontal sinus variables	33/50	66.0	27/50	54.0	60/100	60.0

uniqueness of the sinus pattern for personal identification and did not comment on levels of sex differences. They did, however, present the raw data for males and females (the sex for the sample in Ref. No. 17 was obtained through personal correspondence), and we used this to determine whether significant univariate sex dimorphism existed in their data. Our analyses found no statistical sex differences for any of the variables in the data of Tatlisumak et al.⁷ ($P > 0.50$) and statistical sex differences for three out of eight variables in the data of Tang et al.¹⁷ ($P < 0.05$). LRA of these data yielded a sex allocation accuracy of 61.5% in the former and 72.1%, in the latter, which, again, is similar to our results. As the data in Tatlisumak et al.⁷ did not consist of the supraorbital cells' presence/absence, we deleted this variable from our sample and performed another LRA, which yielded a sex allocation accuracy of 61%. Therefore, the exclusion of supraorbital cells from the logistic regression model marginally increased the sex prediction accuracy (its inclusion had earlier produced a correct allocation in 60% of cases) (Table 2). Considering that the same variable was the only one to exhibit statistically significant inter-observer variation ($P < 0.05$), it appears that one may exclude it from sex differentiation endeavours. Nevertheless, the allocation levels of frontal sinus variables, as a whole, are relatively low and indicate that they may not provide forensically useful information regarding the sex of skeletonised human remains.

The relative lack of sexual dimorphism in the discrete variables has also been indirectly confirmed by others – Uthman et al.¹⁵ evaluated the use of both discrete and continuous variables in sex determination and noted that scallops and septa entered DFA last. However, DFA is not an appropriate statistical method for use on discrete/non-metric variables and our application of LRA is more valid. Indeed, application of LRA by us to the raw data presented in Kirk et al.¹¹ – who used a combination of discrete and continuous variables – shows better sex allocation of the former, but an overall sex prediction accuracy of 62.9%.

Possible reasons for the low sexual dimorphism may be obtained from the studies of Yoshino et al.⁴ and Cox et al.¹⁰ The former believed that frontal sinus' high inter-individual variability rendered them of little value in sex determination. Cox et al.,¹⁰ however, attributed it to limitation of techniques that employ classification systems (such as Yoshino's method). They believe that it is possibly due to loss of relevant information when features that require visual observation are grouped and assigned class numbers. Cox et al.¹⁰ state that this results in "a representation of the frontal sinus that does not capture the degree of variation needed for reliable (sex) identification" (p. 762). They add that codification merely provides a means to perform a quick assessment. While this suggests that more objective quantification of the frontal sinuses may have the potential to reflect sexual dimorphism more accurately, their own study, and another recent report, indicate otherwise – the use of more sophisticated measurement techniques and statistical analyses yielded only moderate levels of accuracy¹⁵ or did not produce any statistically significant sex differences.¹⁰ These denote that, irrespective of the method used, frontal sinus patterns may not reveal male–female differences to levels that can be considered as forensically useful; the application of these sinuses may only be limited for use in circumstances when other, more robust, skeletal parameters are unavailable.

Table 1

Descriptive statistics and Z values for the various frontal sinus variables in females and males.

Variable	Sex	n	Median	Mean Deviation from Median	Z value*
Number of right sinus scallops	Female	50	3	1.34	−0.032
	Male	50	3	1.50	
Number of left sinus scallops	Female	50	3	1.44	−1.562
	Male	50	3	1.34	
Sum of right & left sinus scallops	Female	50	6	2.06	−1.19
	Male	50	6.5	2.24	
Number of right sinus partial septa	Female	50	1	0.72	−0.707
	Male	50	1	0.80	
Number of left sinus partial septa	Female	50	1	0.88	−1.933
	Male	50	1	0.78	
Sum of right & left sinus partial septa	Female	50	1	1.32	−1.572
	Male	50	2	1.38	
Presence/absence of partial septa unilaterally/bilaterally	Female	50	1	0.62	−1.711
	Male	50	2	0.64	
Presence/absence of supraorbital cells unilaterally/bilaterally	Female	50	1	0.70	−0.266
	Male	50	1	0.74	

*None of the variables revealed statistical sexual dimorphism at the $P = 0.05$ level.

Ethical approval

Not applicable since the study was undertaken (retrospectively) on an already available sample of Paranasal Sinus (PNS) view radiographs taken for diagnostic purposes.

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Conflict of interest

None declared.

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